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EVALUATION OF SITE AMPLIFICATION OF ERBAA, TOKAT (TURKEY)

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ABSTRACT

The study area, Erbaa, is one of the largest towns of Tokat with a population of 47000 in the northern part of Turkey. Erbaa is in North Anatolian Fault Zone (NAFZ) and partly located on the Kelkit river plain, also referred to as the Erbaa basin. After the disastrous 1942 earthquake ($M_s=7.2$), the settlement area was seriously damaged and moved farther southwards of its old place in 1944. Dynamic properties of Erbaa soils were determined and shear wave velocity profiles were prepared to be used in site response analyses as part of a microzonation study. During this process, empirically-based shear wave velocities were calculated and site-specific formulas were proposed. 1-D equivalent linear site response analyses were performed in accordance with site-specific grid model using ProSHAKE (v.1.12) software. The amplification ratio was calculated on the basis of site amplification method using soil/bedrock ratio to obtain amplification factors (AF) for the study area. Amplification factors from 1-D site response analyses mostly vary within a range of approximately 1.5-2.5 in the study area.

INTRODUCTION

North Anatolian Fault Zone (NAFZ) is one of the main active seismic zones, which caused destructive earthquakes and related hazards in the northern region of Turkey. The study area, Erbaa, is one of the largest towns of Tokat in the northern part of Turkey. Erbaa is in NAFZ and partly located on the Kelkit river plain, also referred to as the Erbaa basin (Figure 1). After the disastrous 1942 earthquake ($M_s=7.2$), the settlement area was seriously damaged and moved farther southwards of its old place in 1944.

As a part of a microzonation study in Erbaa, shear wave velocity (V_s) values of the geological units exposed in this area were required for site response analyses. The shear wave velocity profiles of Erbaa soils were prepared to be used in site response analyses as part of a microzonation study. 1-D equivalent linear site response analyses were performed using ProSHAKE software. The amplification factors are obtained from these site response analyses.

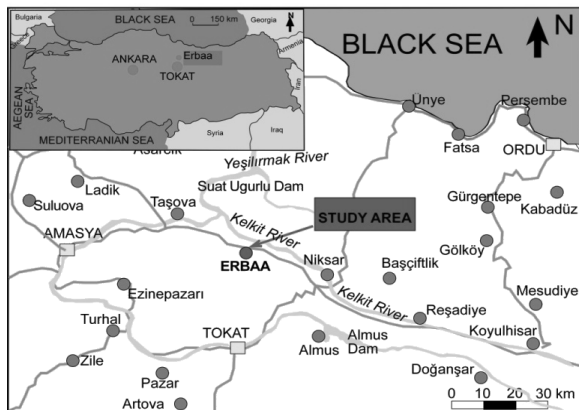


Fig. 1. Location map of the study area

GEOLOGY AND TECTONICS OF THE STUDY AREA

The study area, Erbaa, and its close vicinity are within a pull-apart basin which was formed by the tectonic activity of the North Anatolian Fault Zone (NAFZ). The NAFZ is 1500 km long seismically active right lateral strike slip fault that has a relative motion between the Anatolian Plate and Black Sea Plate (Sengor *et al.*, 1985). Between 1939 and 1967, the NAFZ ruptured by six large, westward-propagating earthquakes with magnitudes greater than 7, and caused approximately 900 km surface break (Allen, 1969; Ketin, 1969; Ambraseys, 1970). The study area, Erbaa, is located on the eastern part of the NAFZ. Surface ruptures of the 1939, 1942 ($M_s=7.2$) and 1943 ($M_s=7.6$) earthquakes occurred in the

Tasova -Erbaa and Niksar basins (Barka *et al.*, 2000). The November, 26, 1943 Tosya earthquake ($M_w = 7.6$) produced 280 km long surface rupture which could be the second longest surface faulting in that sequence (Emre *et al.*, 2006). The Tasova-Erbaa pull-apart basin is approximately 65 km long and 15-18 km wide (Figure 2). The northern margin of the study area is surrounded by the fault segments that ruptured in the 1942 and 1943 earthquakes (Figure 2). The southern part is bounded by the Esencay fault, which has a different morphological expression; however, no instrumental and/or historical earthquakes have been mentioned in the study of Barka *et al.* (2000) related to this fault.

During the 1900s, several earthquakes occurred in this region. Erbaa is considered in the First Degree Earthquake Zone of Turkey (<http://www.deprem.gov.tr/indexen.html>). Erbaa is one of the important seismic areas on the NAFZ with past seismic activity. No seismic activity with higher magnitude has been recorded since 1942 Erbaa-Niksar earthquake in this region.

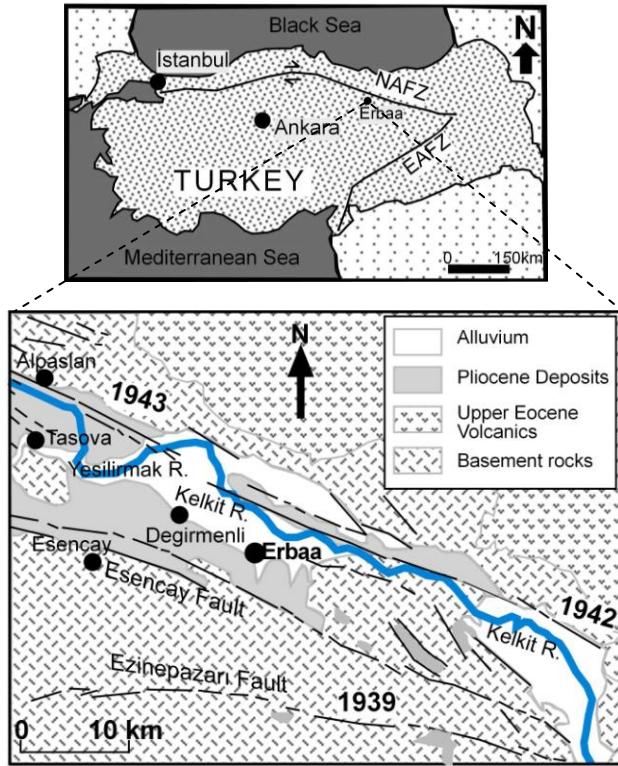


Fig. 2. Geological map of the study area

Metamorphic rocks and the limestone layers as basement rocks can be observed with an age from Permian to Eocene in the study area in a regional macro scale. These rocks are overlaid by Upper Eocene volcanics (basalt, andesite, agglomerate, and tuff) and the alternation of sandstone-

siltstone layers. These units are covered by Pliocene deposits consisting of semi-consolidated clay, silt, sand, and gravel with an unconformity and recent Quaternary alluvial unit (Aktimur *et al.*, 1992) (Figure 2). The Quaternary alluvial unit and Pliocene deposits broadly cover the study area. While the northern part of the settlement area is located on the alluvial unit, the Pliocene deposits dominate the southern part of Erbaa (Yilmaz, 1998) (Figure 2). The alluvium including gravel, sand, and silty clay can be observed in the basement of Kelkit river valleys and in the northern part of the Erbaa basin.

DYNAMIC SOIL PROPERTIES

The measurement of shear wave velocity by in-situ field tests is commonly used in practice. A combination of low strain (e.g. seismic refraction, seismic crosshole and downhole-uphole tests) and high strain (e.g. standard penetration, cone penetration) tests were applied in the study of Bang and Kim (2007). The SPT-based uphole method was proposed for the determination of shear wave velocity using the impact energy generated by SPT test as a source (Kim *et al.*, 2004; Bang and Kim, 2007). The shear wave velocity of the Erbaa soils was determined from SPT-based uphole method at ten different boreholes. The measurement results of ten SPT-based uphole boreholes are evaluated. Besides, several geophysical tests (21 resistivity, 20 seismic refraction, 3 downhole, 10 uphole surveys, and a total of 517 microtremor measurements, 6 Multichannel Analysis Surface Waves (MASW) - Refraction microtremor (REMI), and 30 SCPTU with limited depth are applied to obtain shear wave velocity in the study area.

When shear wave velocity measurements are not available, G_{max} can be estimated using different approaches or empirical formulas. SPT-based G_{max} and/or V_s relationships are most commonly used in the literature (e.g. Ohta and Goto, 1976; Seed *et al.*, 1986). For different soil types, SPT-N and V_s relationships were proposed by different researchers (e.g. Ohba and Toriumi, 1970; Imai and Yoshimura, 1970, etc.). The SPT-N values obtained from Erbaa soils are used in these equations to empirically determine shear wave velocity (V_s) for each borehole.

The shear wave velocities obtained from SPT-based uphole tests (measured shear wave velocity) are compared to empirical results for different soil types. New empirical relationships between SPT-N and V_s are proposed for different alluvial and Pliocene soils in the study area in accordance with the SPT-based uphole measurements as well (Akin, 2009; Akin *et al.*, 2011).

V_{s30} values are calculated for each borehole using the actual V_s data where it was available. Nevertheless, some boreholes in the study area do not reach to 30 m depth. Considering the

smooth curve between the deepest data and 30 m, SPT-based uphole boreholes are evaluated and the relationships of V_s values are proposed for each borehole to estimate V_{s30} by extrapolation.

Moreover, the V_{s30} soil profiles are also evaluated in terms of NEHRP site classification category. As a result, the V_{s30} values in the study area range between 180 and 360 m/s representing D type soil in accordance with NEHRP classification. D type soils can be classified as stiff soils. On the contrary, if the CGS (California Geological Survey) classification is considered, the soils in the study area can be distinguished in between C and D soil type. The distribution of V_{s30} values in the study area is presented in Figure 3.

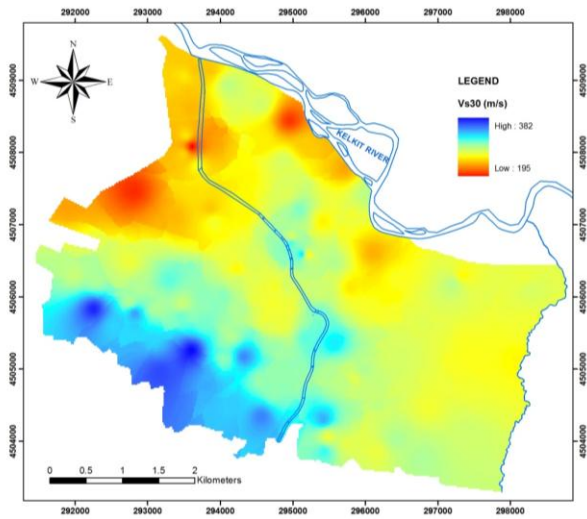


Fig. 3. V_{s30} map of the study area

SITE RESPONSE ANALYSES

One-dimensional site response analyses are based on the assumption that all boundaries are horizontal and the response of a soil deposit is caused by SH-waves propagating vertically from the underlying bedrock (Kramer, 1996). ProSHAKE (v.1.12) (EduPro Civil Systems) is used to perform 1-D equivalent site response analyses in this study. ProSHAKE (v.1.12) is a powerful, user-friendly computer program for one-dimensional, equivalent linear ground response analysis. The features of this software are highly compatible and allow evaluating modulus reduction and damping models. The graphical display of soil profile and input motion parameters, graphical display of a wide variety of output parameters, and animation of ground response are other advantages of ProSHAKE (v.1.12) software.

Firstly, the data from 104 boreholes are evaluated for site response analyses. Then, the shear wave velocity profile for each borehole is defined by dividing the soil profile into 3 m (for $z < 100$ m) or 5 m (for $z > 100$ m) sublayers. Alluvial and Pliocene soil deposits are individually evaluated in four main soil groups: A1-Clay (alluvium clay), A2-Sand (alluvium sand), P1-Clay (Pliocene clay) and P2-Sand (Pliocene sand). The gravelly and silty soil layers are also considered. Instead of using default models, the essential modulus reduction and damping curves are calculated to model the soil units in the study area.

Modulus reduction and damping curves are needed to perform equivalent linear 1-D site response analysis. Hence, proper modulus reduction and damping curves are established using the Darendeli model (Darendeli, 2001) in this study. Accordingly, the model is re-formulated with different confining pressures and the curves are similar to the EPRI (Electric Power Research Institute) curves. So, site-specific soil models are established producing modified G/G_{max} -shear strain curves in this study. The G/G_{max} -shear strain curves are produced for the four previously defined soil groups. The representative depths (in meters) are taken into consideration during the calculations to reflect different confining pressures.

Dividing a study area into grid cells is a common practice in seismic microzonation applications. The dimension of grid cells mostly depends upon the availability of geological, geophysical and geotechnical data for the investigated area. The most common grid sizes in the literature are 500 m x 500 m or 250 m x 250 m. Site characterization can be performed based on grid system using the available data for each cell by some authors (Matsuoka et al., 2006; Erdik et al., 2005; Ansal et al., 2006; Ansal and Tonuk, 2007). Therefore, the study area, Erbaa settlement, is divided into 500 m x 500 m grid cells and seismic response analysis is performed for each cell. A total of 118 grid cells are formed for the study area (Figure 4). Afterwards, the results of representative soil profiles are statistically extrapolated for the entire study area. The available data for each cell is used in site response analysis. For empty cell or unavailable data conditions, the nearest borehole data are used in order to perform site response analysis. As a result, a total of 118 soil profiles are obtained for the site response analyses.

The bedrock profiles are determined on the basis of the constant shear wave velocity ($V_s=760$ m/s). Ansal and Tonuk (2007) mentioned that the shear wave velocity profiles should be established down to the depth of engineering bedrock with an estimated shear wave velocity of 700-750 m/s. However, B and C type soil boundary in NEHRP starts with 760 m/s indicating the boundary value of bedrock shear wave velocity. The same boundary value ($V_s=760$ m/s) is accepted as bedrock shear wave velocity in Erbaa for the site response analyses.

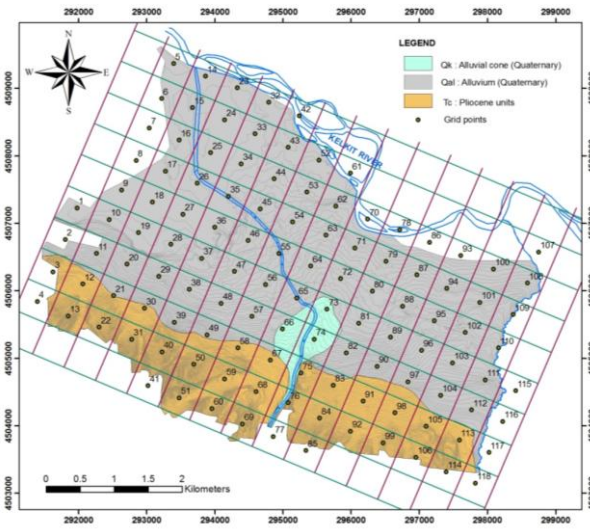


Fig. 4. Grid system used for site response analysis in this study

EVALUATION OF AMPLIFICATION VALUES

Site amplification is one of the important factors controlling damage in urban areas during strong earthquakes. Site conditions can be determined by site classifications for ground motion amplification purposes. Site classifications can be determined by means of surface geology, geotechnical data, and/or V_{s30} values to define amplification factors (Kramer and Stewart, 2004).

Site response analyses are performed using different approaches in Erbaa as mentioned before. The obtained results from 1-D equivalent linear model using ProSHAKE (v.1.12) software are firstly evaluated. Furthermore, shear wave velocities are used to obtain amplification values using amplification equations in the literature.

The time-histories obtained from site response analyses can be used as the representative time-histories of surface motions. The direct use of response spectra of calculated surface motions is generally not preferred in practice. However, it is advantageous to obtain site amplification ratio from ground response analyses. Site amplification ratio is the ratio between response spectra of ground surface motions computed from ground response analyses and the response spectra of corresponding input rock motions. The time-histories obtained from ground response analyses can be used directly to represent ground surface motions, or synthetic time-histories can be developed to match the design ground surface response spectrum (U.S. Army Corps of Engineers, 1999).

In the site response analyses of Erbaa, input ground motions are considered using PGA values as given in Table 5.8. Afterwards, the ratio is calculated on the basis of site amplification ratio method using soil/bedrock ratio (Borcherdt, 1970) as given in Equation 1 to obtain amplification ratios (AF) for the study area.

$$AF = \frac{IM_{\text{soil}}}{IM_{\text{rock}}} \quad (1)$$

where IM : Intensity Measure

The distribution of selected input ground motions are depicted for BH-4 in Figure 5. The surface time histories obtained from the site response analyses are illustrated in Figure 6.

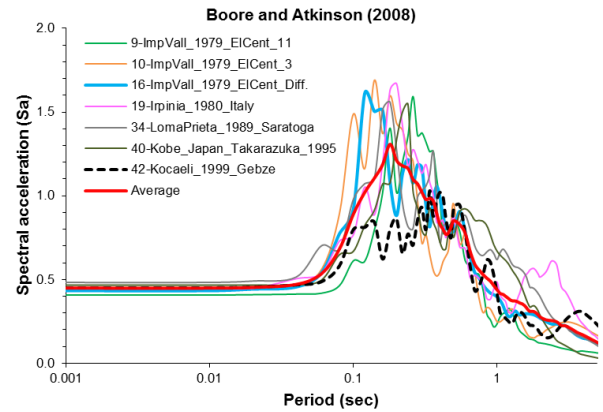


Figure 5. Input response spectra of BH-4 based on Boore and Atkinson (2008) model for 0 km distance zone

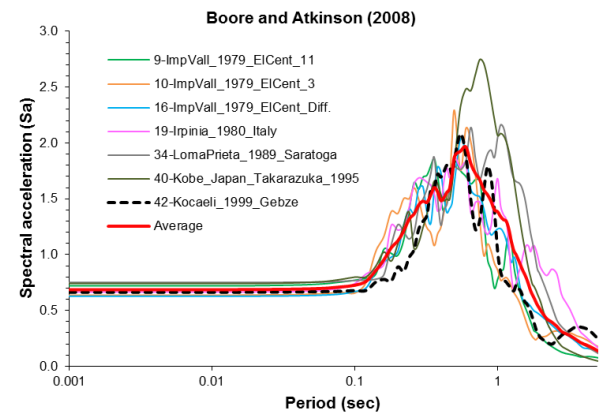


Figure 6. Surface response spectra of BH-4 based on Boore and Atkinson (2008) model for 0 km distance zone

The calculated amplification ratios are also shown in Figure 7 with respect to Boore and Atkinson (2008) (BA08) model as indicated in the previous sections which has been introduced that the input motions are scaled to be compatible with BA08 model. It should be noted that different distance zones are also considered during the site response analysis.

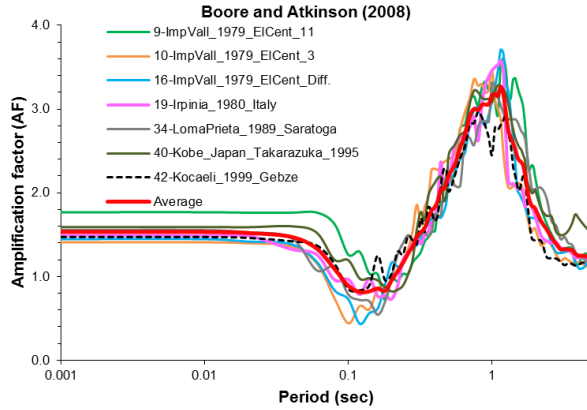


Figure 7. Amplification ratio of BH-4 based on Boore and Atkinson (2008) model for 0 km distance zone

The peak ground acceleration (PGA) from surface motions and amplification maps are prepared using the obtained data from the site response analysis based on the aforementioned 118 grid points in the grid system (Figures 8, 9, 10, and 11).

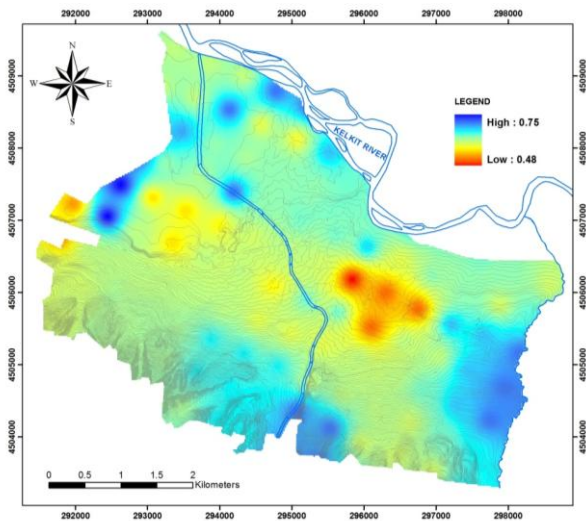


Figure 8. Peak ground acceleration (PGA) (surface) map of the study area based on Boore and Atkinson (2008) model

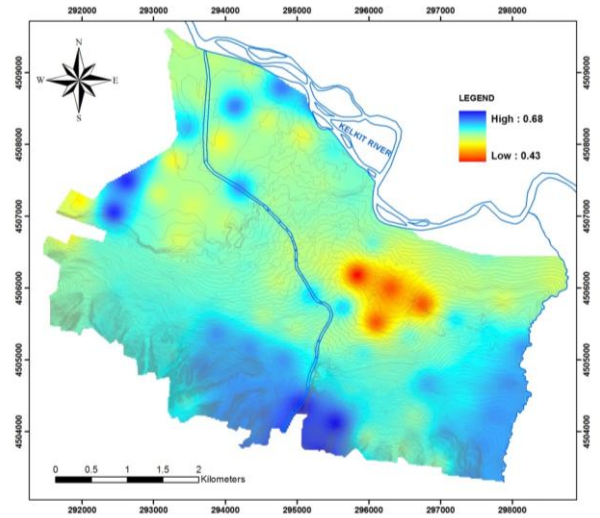


Figure 9. Peak ground acceleration (PGA) (surface) map of the study area based on Campbell and Bozorgnia (2008) model

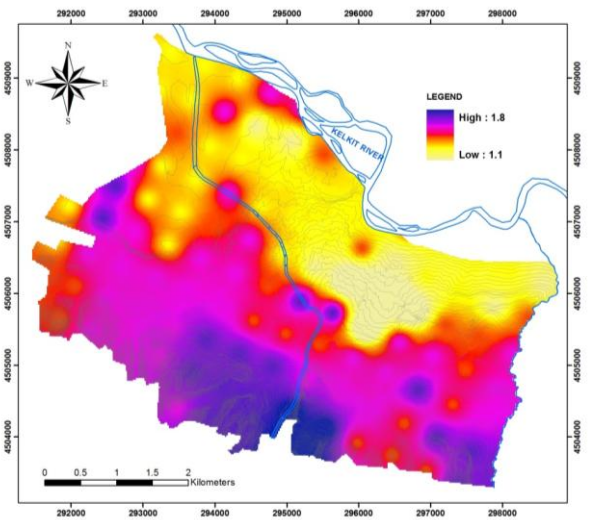


Figure 10. Amplification map of the study area based on Boore and Atkinson (2008) model (for 0.001 sec)

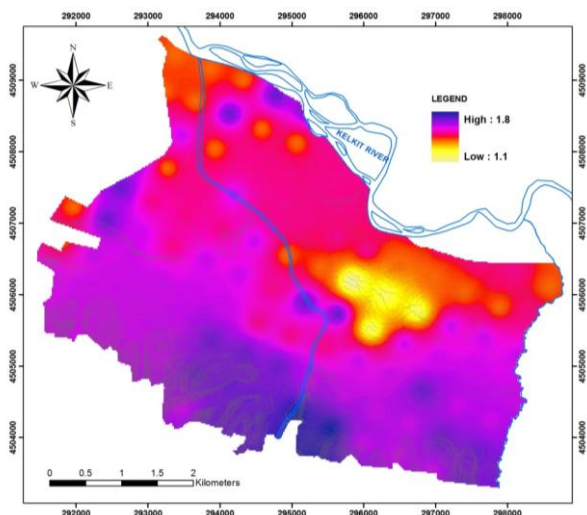


Figure 11. Amplification map of the study area based on Campbell and Bozorgnia (2008) model (for 0.001 sec)

CONCLUSIONS

Dynamic properties of Erbaa soils are determined and shear wave velocity profiles are prepared to be used in site response analyses. During this process, empirical based shear wave velocities are calculated and site-specific formulas are proposed.

1-D equivalent linear site response analyses are performed in accordance with site-specific grid model using ProSHAKE (v.1.12) software. In the site response analyses of Erbaa, input ground motions are considered using PGA values. Afterwards, the ratio is calculated on the basis of site amplification method using soil/bedrock ratio to obtain amplification factors (AF) for the study area.

Amplification factors from 1-D site response analyses and from different empirical approaches mostly vary within a range of approximately 1.5-2.5 in the study area.

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